# Characterizing and Simulating the Performance of the Physical Layer of Data Vortex Switching Nodes

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## Introduction

Photonic packet switching fabrics are emerging as an attractive solution for ultra-high bandwidth, low switching latency interconnection within next-generation high-performance computing architectures. This is because lightwave networks are not limited by the conventional bottlenecks found in electronic systems, and have demonstrated the transmission of gargantuan volumes of data [1]. Furthermore, by utilizing intelligent routing procedures, the latency of such networks can be reduced to speed-of-light limitations. A topology for a switching fabric with minimal routing logic, designed specifically for photonic implementation, has been recently demonstrated and evaluated [2-4]. Termed the Data Vortex, this topology employs implicit synchronous signaling and routing, thereby eliminating the need for optical buffering.

The predominant switch elements considered for optical packet networks have been semiconductor optical amplifiers (SOAs) due to their fast switching times, low switching power, and high extinction ratio [5]. Furthermore, in addition to switching, SOAs may be configured to re-amplify the signal and compensate for routing and transmission losses. The primary limitation of SOAs is the in-band signal noise introduced due to amplified spontaneous emissions (ASE). Crosstalk and other effects also contribute to an increase in the signal's bit error rate (BER) as it propagates through the switching nodes [6].

The present work characterizes and simulates signal propagation through the physical layer of the Data Vortex switching fabric. Because traditional time-domain physical modeling techniques such as those based on rate equations, traveling wave analyses, and transfer matrix methods (*viz.* [6-8]) require precise knowledge of a myriad of physical parameter values, they are often quite difficult to implement. Instead of relying on physical analyses, we capture the essence of the signal distortions and perform the modeling from a signal-level phenomenological perspective. In order to construct the model, experimental data was collected from a number of actual Data Vortex switching nodes using optical packets with 10Gbit/sec payloads. It should also be noted that the methodology described herein can be applied to systems with differing architectures in a straightforward manner.

## Experimental Setup

A single node of the Data Vortex shown in Fig. 1 is constructed with two SOAs configured as a 1x2 switch element. Post-amplification optical isolators are incorporated in an effort to limit backscattering. Optical packets with 10Gbit/sec payload data are injected into one of the node's input ports. The SOAs are tuned such that the identically compensate the coupling and connection losses in the node. The optical spectrum of the payload is measured after one and two hops through the node. With each hop the optical spectrum is distorted and accumulates a noise floor, primarily as a result of the ASE noise from the SOA switch. The measured spectra are shown in bold in Fig. 2 panels A-C.

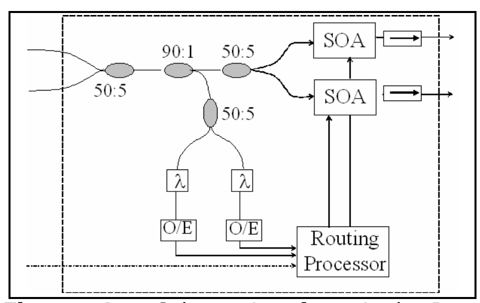


**Figure 1.** Schematic of a single Data Vortex switching node (after [2-4]).

## Modeling and Simulation

The numerical model for the Data Vortex switch fabric is now constructed from the measured spectral data at the input and output of a single node. The model can then be employed to predict the signal evolution through consecutive switching nodes. A simple lineshape is initially fit to the signal. Zero-mean Gaussian noise components ("white noise") are then added to the idealized signal frequency components such that the simulated spectra resemble the experimental ones. The prominent features captured by this numerical process are the signal amplitudes, the spectral width of each, and the intensity of the noise floor. These numerically produced spectra are compared with the measured data in Fig. 2 panels A and B.

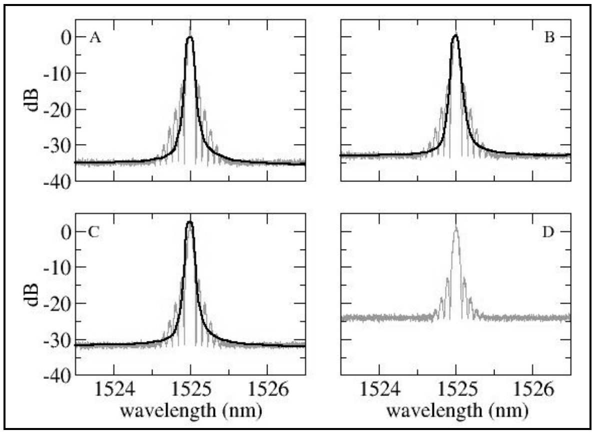


**Figure 2.** Panel A illustrates the experimentally-observed (dark) and simulated (light) input spectra; Panels B and C compare these spectra after one and two nodes, respectively. Panel D presents the projected spectrum after propagation through 20 nodes.

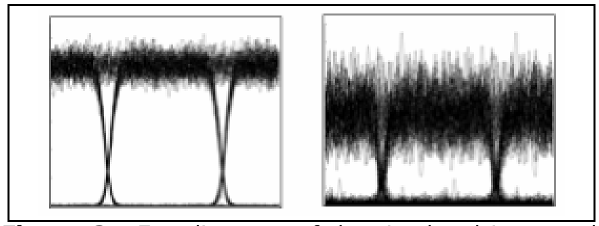

**Figure 3.** Eye diagrams of the simulated input and output signals after propagation through 20 nodes.

The numerical model predicts the data stream evolution through the switching fabric. Figure 2 panel C depicts the progression of a simulated spectrum as it traverses two switching nodes. The results agree well with the experimentally collected data shown in bold. In Fig. 2 panel D the model projection for propagation through 20 consecutive nodes is shown.

The modeling technique easily allows for spectral data to be transformed into time-domain signals so that the Q-factor and bit error rate (BER) can be extracted (see Fig. 3). These key measures of system performance enable the physical layer design of large scale switching fabrics.

**Conclusion**

A novel technique for modeling of lightwave switching networks has been developed. Because it is often difficult to precisely determine the values of physical parameters like the carrier concentrations and the Einstein coefficients, the focus has instead been placed on the signal spectrum and its degradation as it traverses the switching element nodes of the network. The utility of signal-level phenomenological modeling has been demonstrated. Predictions have accordingly been made about the result of cascading numerous switching nodes without requiring the complexities of complete physical analyses. In future work, additional effects such as WDM cross-gain modulation could be incorporated.

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